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**CALCULATION OF THE IMPULSE RESPONSE
IN A TRANSMISSION WHICH IS
TERMINATED BY ITS
CHARACTERISTIC IMPEDANCE
Nils Haaheim
December 1969**

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Interpretation Division, Institute
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**CALCULATION OF THE IMPULSE RESPONSE IN
A TRANSMISSION LINE WHICH IS TERMINATED BY
ITS CHARACTERISTIC IMPEDANCE**

by

Nils Haaheim

Institute for Transmission Techniques

ELAB Report TR-90

August 1967

Technical report

for

**project 440165 NTNF's division of space activities
and project 440117, NTNF B 1950**

[NTNF: Norwegian Council of Scientific & Industrial Research]

**Electronics laboratory at NTH
associated with SINTEF
Norwegian Technical University
Trondheim**

**[NTH: Norwegian Technical University]
[SINTEF: Society for Industrial & Technical Research]**

INTRODUCTION

This report is the result of an investigation relating to the transmission of data over a cable. The basis of the task consisted in finding out how an impulse that was imposed by means of a current generator on one end of a cable was put out at the other end of the cable. The cable is assumed to be terminated by its characteristic impedance at both ends. It is considered that the primary parameters R and G are frequency dependent. The variations in L and C are so small that the latter have been regarded as constants, and this leads to the non-inclusion of the small roundings-off that in practice occur at the beginning of the impulse. A program has been prepared for calculation of the responses on the GIER calculating machine.

The work has been carried out with financial assistance from the Electronics Laboratory at NTH.

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1. General

For a homogeneous transmission line one has:

a. the motion-constant

$$v = \frac{1}{\sqrt{C}} = \sqrt{\frac{1}{(R + j\omega L)(G + j\omega C)}}$$

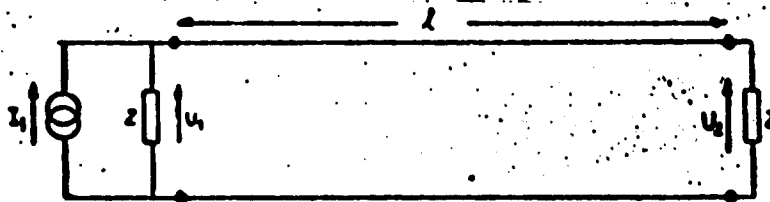
b. characteristic impedans

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

where R. G. L and C are the line's primary parameters. To a line which is terminated by its characteristic impedance, what is applicable is

$$\frac{U_2}{U_1} = H(j\omega) = e^{-\gamma l}$$

where l is the line's length.



The line has one unit's impulse imposed

$$U_1(j\omega) = \frac{1}{j\omega}$$

and one obtains the Fourier transformation of the output voltage

$$u_2(j\omega) = u_1(j\omega)H(j\omega) = \frac{1}{j\omega} e^{-\gamma(j\omega) \cdot l}$$

or in the time-plane

$$u_2(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{1}{j\omega} e^{-\gamma(j\omega) \cdot l} e^{j\omega t} d\omega$$

The Laplace transformation of the output voltage is

$$u_2(s) = \frac{1}{s} e^{-\gamma(s) \cdot l}$$

2. Frequency-independent parameters

Equation 7 can be inverse-transformed on the assumption that the line parameters are frequency-independent (See for example Weber [WE 1] pages 378-384, and gives

$$u_2(t) = e^{-\frac{t}{\tau}} u_1\left(t - \frac{l}{u}\right) + \frac{l}{u} \int_{t-l/u}^t \frac{e^{-\tau/\tau}}{\tau^2 - (l/u)^2} I_1\left[\frac{\tau^2 - (l/u)^2}{2\tau(l/u)}\right] d\tau$$

where one has introduced

$$u = \frac{1}{\sqrt{L C}}$$

$$e = \frac{1}{2} \left(\frac{R}{L} + \frac{G}{C} \right)$$

$$e = \frac{1}{2} \left(\frac{R}{L} - \frac{G}{C} \right)$$

and $u(t_{\frac{L}{u}})$ is unit's impulse for $t = \frac{L}{u}$. Equation 8 is calculated on the digital calculating machine (GIER) and the result of the calculation for a BF-telephone cable of 1 km length and with parameters (See [GR 1] page 29) $R = 31.6$ ohm/km, $L = 0.9$ mH/km, $G = 2$ μ S/km, and $C = 0.028$ μ F/km is shown in Fig. 2.

For calculation of the modified Bessel-function $I_1(x)$ there has been used the serial development of $x^{-1} I_1(x)$ which is applicable to $-3.75 \leq x \leq 3.75$, taken from the "Handbook of Mathematical Functions," Dover 1965, page 378, formula 9.8.3.

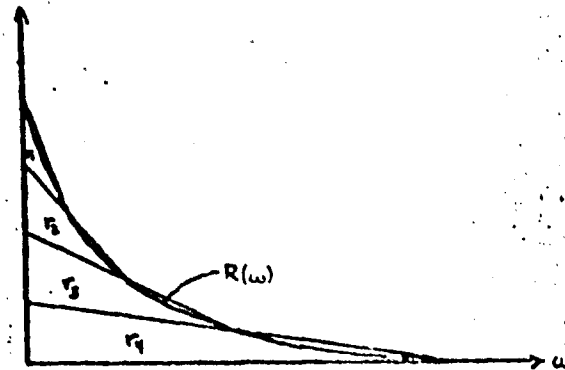
3. Frequency-dependent R and G

For causal time-functions ($f(t)=0$ for $t<0$) the time-response can be calculated from the real or the imaginary component of the Fourier-transformation ([PA 1] page 13)

$$F(j\omega) = R(\omega) + jX(\omega)$$

$$f(t) = \frac{2}{\pi} \int_0^{\infty} R(\omega) \cos \omega t d\omega - \frac{2}{\pi} \int_0^{\infty} X(\omega) \sin \omega t d\omega$$

Depending on the form of $R(\omega)$, one can choose various methods for numerical calculation of $f(t)$. If $R(\omega)$ is concave, it can be approximated by means of triangles as shown in Fig. 3. [PA 1, page 58]



One then obtains

$$R(\omega) = r_1(\omega) + r_2(\omega) + \dots$$

and the resulting time-response then is

$$f(t) = g_1(t) + g_2(t) + \dots$$

where $g_i(t)$ is the time-function corresponding to $r_i(\omega)$.

We will now find the time-function which corresponds with a spectrum where the real component is triangular as shown in Fig. 4a.

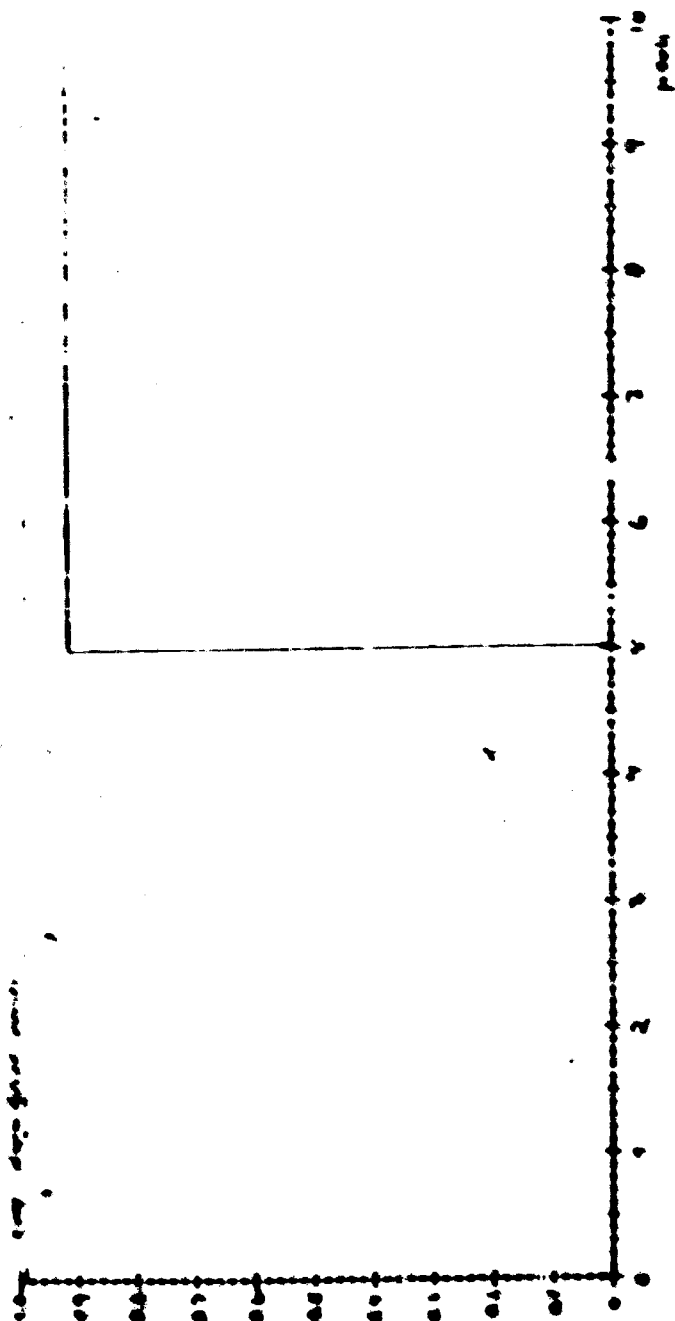
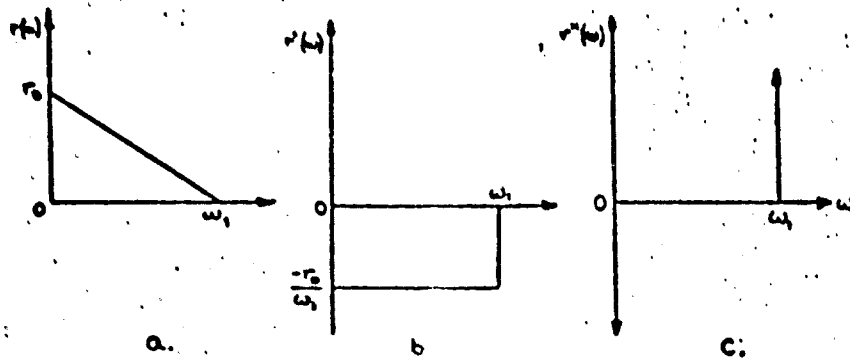


Fig. 2 The impulse response of a cable terminated by its characteristic impedance, when the primary parameters R , L , C and G are frequency-independent.

$\frac{1}{2} \text{ sec}$
10



The derivate, $r^1(\omega)$, is shown in Fig. 4b and the double-derivate in Fig. 4c.

For a Fourier-pair the applicable equations are

$$\left. \begin{aligned} f(t) &\longleftrightarrow F(\omega) = R(\omega) + jX(\omega) \\ tf(t) &\longleftrightarrow j \frac{dF}{d\omega} = jR'(\omega) - X'(\omega) \\ t^2 f(t) &\longleftrightarrow -\frac{d^2 F}{d\omega^2} = -R''(\omega) - jX''(\omega) \end{aligned} \right\}$$

from which we obtain (See Equation 11)

$$\begin{aligned} tf(t) &= -\frac{2}{\pi} \int_0^\infty R'(\omega) \sin \omega t d\omega \quad t > 0 \\ t^2 f(t) &= -\frac{2}{\pi} \int_0^\infty R''(\omega) \cos \omega t d\omega \quad t > 0 \end{aligned}$$

We now have (See Fig. f)

$$r(t) = \frac{1}{2} (r(t_1) + r(t_2))$$

which gives (Equation 16)

$$\begin{aligned} r(t) &= \frac{1}{2} \int_0^1 (r(t_1) + r(t_2)) \cos \theta \, d\theta \\ &= \frac{1}{2} (1 + \cos \theta) = 1 \end{aligned}$$

One in that case obtains

$$r(t) = \frac{1}{2} \frac{1 + \cos \theta}{1} = \frac{1}{2} \frac{1 + \cos^2(\theta/2)}{1} = 1$$

This function is illustrated by Fig. 5



NOT REPRODUCIBLE

In Fig. 6 is shown the course of the real component of the transmission function for a 1.2 mm BF cable of 1 km length and with parameters

$$L = 0.9 \quad \text{mH/km}$$

$$C = 0.028 \quad \mu\text{F/km}$$

and R and G frequency-dependent

f (kHz)	R (Ω /km)	G (μS /km)
3	31.6	2
12	32.2	8.5
60	43.5	42
108	56	76
156	66	111
204	75	144
252	83	178
500	117	354
1000	166	706
2000	235	1412
5000	370	3530
10000	525	7000
15000	640	10500
25000	830	17600
50000	1170	35000

The parameters are taken from Grønlie [GR 1] page 29 and several values are calculated from G being proportional to f and R being proportional to \sqrt{f} .

As appears from Fig. 6, the real component is concave and can be approximated with a triangle, as mentioned. The term which represents the constant phase-contribution is deducted, but it is taken into consideration later when calculating the impulse response. The sum of the inverse-transformations of individual contributions from the triangles gives the cable's impulse response.

On numerical integration of this sum, one finds thus the impulse response of the cable.

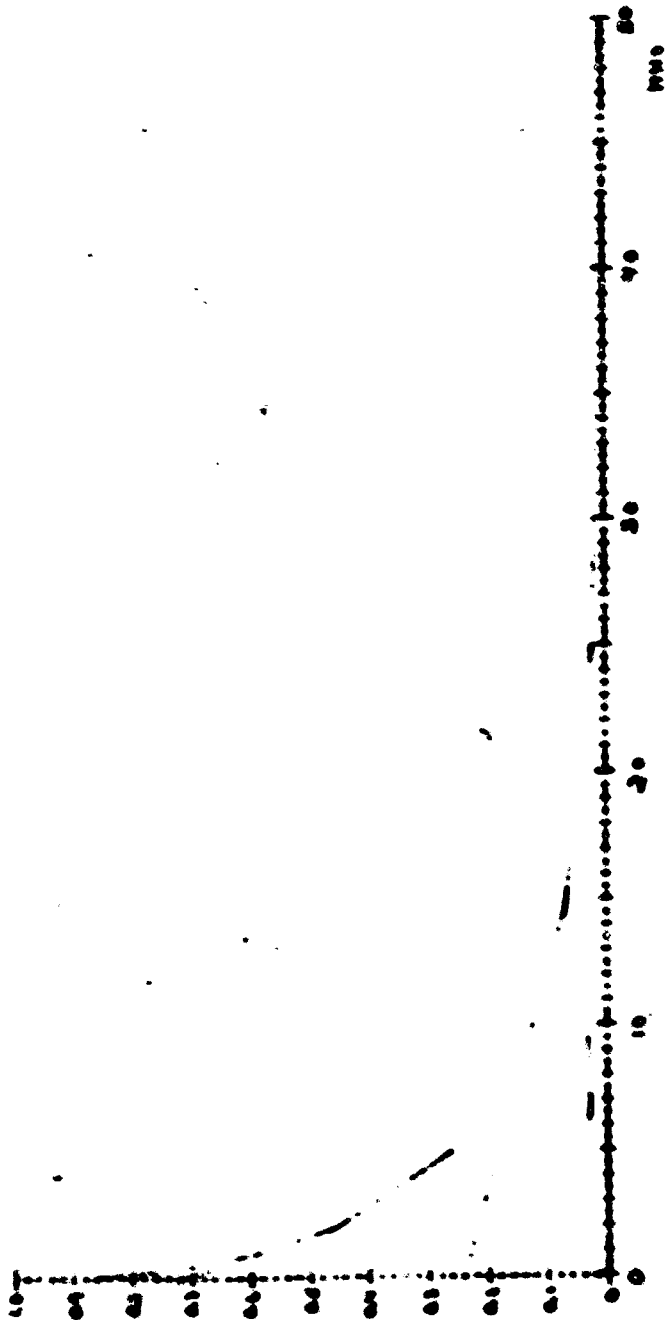


Fig. 6 The real component of the transmission function approximated with triangles.

4. Program descriptions

Three different programs have been written in GIER
algol III.

4.1. Calculation of the impulse response in a cable on the assumption of constant parameters.

The method is described in Para. 2.

Data strip:

R(ohm/km)

L(H/km)

G(S/km)

C(F/km)

cable length in km

the length of the time-axis in secs.

The result is obtained on the plotter on GIER I.
The pen must be placed 1-2 cm from the left edge of the
sheet before the calculation begins. Program write-out,
or transcript, and example are appended. Procedure lin-
scale is utilized in the program and does appear on the
strip, but not on the transcript. An example is shown
in Fig. 2.

4.2. Calculation of the real component of the transmission function.

The program is utilized to calculate the real com-
ponent of the transmission function

$$R(\omega) = R_0(e^{-\gamma(\omega) \cdot l})$$

and can be utilized to obtain an impression of how many frequency values one will use for the next program and how the latter will be chosen.

Data strip:

L(H/km)

C(F/km)

cable length in km

number of frequency values

f_1 (Hz) , R_1 (ohm/km) , G_1 (S/km)

f_2 , R_2 , G_2

and so on.

The result is plotted on the plotter connected to GIER I.

An example is shown in Fig. 6.

The program transcript is appended, but procedure linscale is not included in the transcript.

4.3. Calculation of the impulse response when R and G are frequency-dependent.

The program calculates the impulse response in accordance with the method which is described in Para. 3.

Data strip: (See also Para 4.2.)

L(H/km)

C(F/km)

cable length in km

the step-length for integration in sec.

the length of the time-axis in sec.

number of frequency values

f_1 (Hz) , R_1 (ohm/km) , G_1 (S/km)

f_2 , R_2 , G_2

and so on.

The result is plotted on the plotter connected to GIER I. In order to examine the accuracy of the integration, one needs to work with two different step-lengths as shown in the following example where one has used step-length 5 nsec. and 2.5 nsec. Transcription of the data-strips appears on the next page and the result of the calculation in Fig. 7. As appears from the figures, the derivations between the two curves are very small, and the result will be satisfactory for most practical purposes. Here one will also have the benefit of the program which calculates the course on the assumption of frequency-independent parameters (Para. 4.1.) which gives the asymptotic course. On the typewriter four numbers are transcribed, namely:

1. The time-delay

2. The stationary value of the impulse

- 3 and 4 are real value for the transmission function in the case of the first and last frequency.

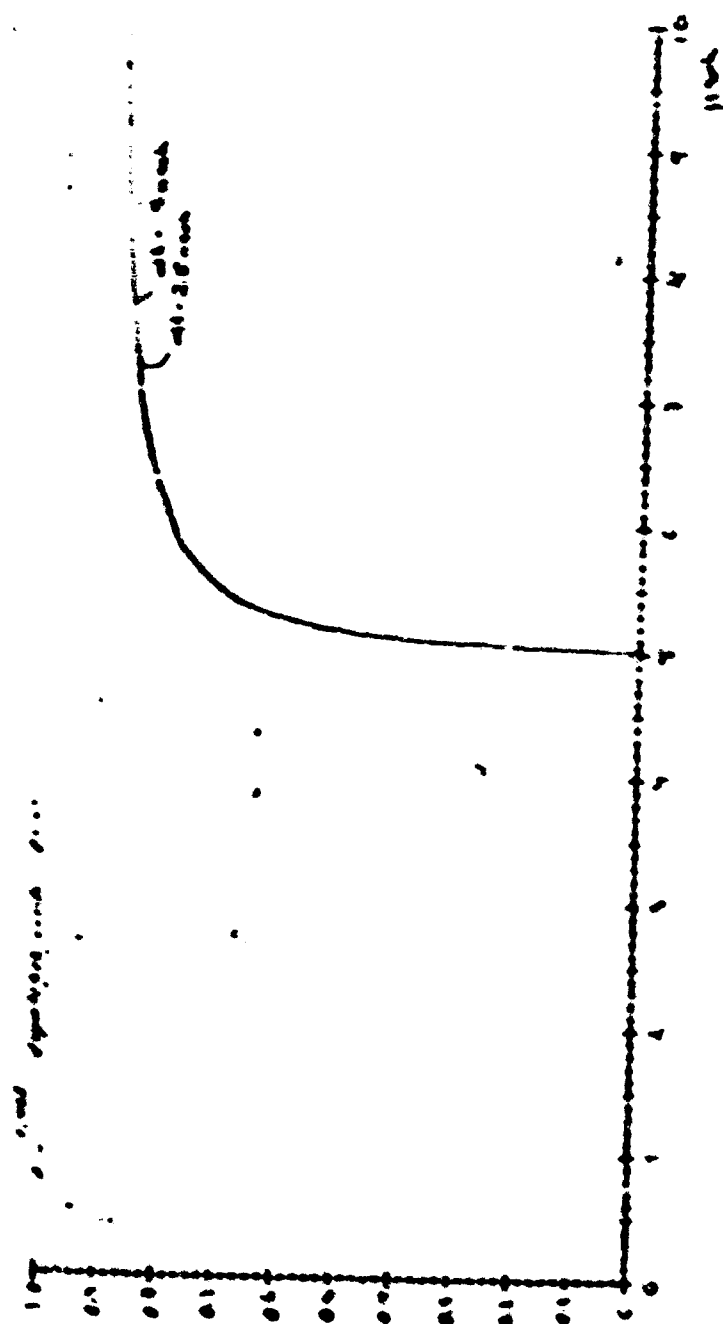


Fig. 7 The impulse response of a
1 km-long BP-cable.

The impulse response of a cable, on the assumption that the primary parameters R , L , G and C are frequency-independent.

1. NAME _____
2. DATE _____
3. TIME _____
4. PLACE _____
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2. und 3. 11. 1947
Hilfskassen

Data strip:

MAX = 1 SEC

NOT REPRODUCIBLE

The real component of the transmission function.

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100  DIMENSION A(10), B(10), C(10), D(10), E(10), F(10), G(10), H(10), I(10), J(10)
110  DATA A, B, C, D, E, F, G, H, I, J
120  DIMENSION K(10), L(10), M(10), N(10), O(10), P(10), Q(10), R(10), S(10), T(10)
130  DATA K, L, M, N, O, P, Q, R, S, T
140  DIMENSION U(10), V(10), W(10), X(10), Y(10), Z(10), AA(10), AB(10), AC(10), AD(10)
150  DATA U, V, W, X, Y, Z, AA, AB, AC, AD
160  DIMENSION AE(10), AF(10), AG(10), AH(10), AI(10), AJ(10), AK(10), AL(10), AM(10), AN(10)
170  DATA AE, AF, AG, AH, AI, AJ, AK, AL, AM, AN
180  DIMENSION AO(10), AP(10), AQ(10), AR(10), AS(10), AT(10), AU(10), AV(10), AW(10), AX(10)
190  DATA AO, AP, AQ, AR, AS, AT, AU, AV, AW, AX
200  DIMENSION AY(10), AZ(10), BA(10), BB(10), BC(10), BD(10), BE(10), BF(10), BG(10), BH(10)
210  DATA AY, AZ, BA, BB, BC, BD, BE, BF, BG, BH
220  DIMENSION BI(10), BJ(10), BK(10), BL(10), BM(10), BN(10), BO(10), BP(10), BQ(10), BR(10)
230  DATA BI, BJ, BK, BL, BM, BN, BO, BP, BQ, BR
240  DIMENSION BS(10), BT(10), BU(10), BV(10), BW(10), BX(10), BY(10), BZ(10), CA(10), CB(10)
250  DATA BS, BT, BU, BV, BW, BX, BY, BZ, CA, CB
260  DIMENSION CC(10), CD(10), CE(10), CF(10), CG(10), CH(10), CI(10), CJ(10), CK(10), CL(10)
270  DATA CC, CD, CE, CF, CG, CH, CI, CJ, CK, CL
280  DIMENSION CM(10), CN(10), CO(10), CP(10), CQ(10), CR(10), CS(10), CT(10), CU(10), CV(10)
290  DATA CM, CN, CO, CP, CQ, CR, CS, CT, CU, CV
300  DIMENSION CW(10), CX(10), CY(10), CZ(10), DA(10), DB(10), DC(10), DD(10), DE(10), DF(10)
310  DATA CW, CX, CY, CZ, DA, DB, DC, DD, DE, DF
320  DIMENSION DG(10), DH(10), DI(10), DJ(10), DK(10), DL(10), DM(10), DN(10), DO(10), DP(10)
330  DATA DG, DH, DI, DJ, DK, DL, DM, DN, DO, DP
340  DIMENSION DQ(10), DR(10), DS(10), DT(10), DU(10), DV(10), DW(10), DX(10), DY(10), DZ(10)
350  DATA DQ, DR, DS, DT, DU, DV, DW, DX, DY, DZ
360  DIMENSION EA(10), EB(10), EC(10), ED(10), EE(10), EF(10), EG(10), EH(10), EI(10), EJ(10)
370  DATA EA, EB, EC, ED, EE, EF, EG, EH, EI, EJ
380  DIMENSION EK(10), EL(10), EM(10), EN(10), EO(10), EP(10), EQ(10), ER(10), ES(10), ET(10)
390  DATA EK, EL, EM, EN, EO, EP, EQ, ER, ES, ET
400  DIMENSION EU(10), EV(10), EW(10), EX(10), EY(10), EZ(10), FA(10), FB(10), FC(10), FD(10)
410  DATA EU, EV, EW, EX, EY, EZ, FA, FB, FC, FD
420  DIMENSION FE(10), FF(10), FG(10), FH(10), FI(10), FJ(10), FK(10), FL(10), FM(10), FN(10)
430  DATA FE, FF, FG, FH, FI, FJ, FK, FL, FM, FN
440  DIMENSION FO(10), FP(10), FQ(10), FR(10), FS(10), FT(10), FU(10), FV(10), FW(10), FX(10)
450  DATA FO, FP, FQ, FR, FS, FT, FU, FV, FW, FX
460  DIMENSION FY(10), FZ(10), GA(10), GB(10), GC(10), GD(10), GE(10), GF(10), GG(10), GH(10)
470  DATA FY, FZ, GA, GB, GC, GD, GE, GF, GG, GH
480  DIMENSION GI(10), GJ(10), GK(10), GL(10), GM(10), GN(10), GO(10), GP(10), GQ(10), GR(10)
490  DATA GI, GJ, GK, GL, GM, GN, GO, GP, GQ, GR
500  DIMENSION GS(10), GT(10), GU(10), GV(10), GW(10), GX(10), GY(10), GZ(10), HA(10), HB(10)
510  DATA GS, GT, GU, GV, GW, GX, GY, GZ, HA, HB
520  DIMENSION HC(10), HD(10), HE(10), HF(10), HG(10), HH(10), HI(10), HJ(10), HK(10), HL(10)
530  DATA HC, HD, HE, HF, HG, HH, HI, HJ, HK, HL
540  DIMENSION HM(10), HN(10), HO(10), HP(10), HQ(10), HR(10), HS(10), HT(10), HU(10), HV(10)
550  DATA HM, HN, HO, HP, HQ, HR, HS, HT, HU, HV
560  DIMENSION HW(10), HX(10), HY(10), HZ(10), IA(10), IB(10), IC(10), ID(10), IE(10), IF(10)
570  DATA HW, HX, HY, HZ, IA, IB, IC, ID, IE, IF
580  DIMENSION IG(10), IH(10), II(10), IJ(10), IK(10), IL(10), IM(10), IN(10), IO(10), IP(10)
590  DATA IG, IH, II, IJ, IK, IL, IM, IN, IO, IP
600  DIMENSION IQ(10), IR(10), IS(10), IT(10), IU(10), IV(10), IW(10), IX(10), IY(10), IZ(10)
610  DATA IQ, IR, IS, IT, IU, IV, IW, IX, IY, IZ
620  DIMENSION JA(10), JB(10), JC(10), JD(10), JE(10), JF(10), JG(10), JH(10), JI(10), JJ(10)
630  DATA JA, JB, JC, JD, JE, JF, JG, JH, JI, JJ
640  DIMENSION JK(10), JL(10), JM(10), JN(10), JO(10), JP(10), JQ(10), JR(10), JS(10), JT(10)
650  DATA JK, JL, JM, JN, JO, JP, JQ, JR, JS, JT
660  DIMENSION JU(10), JV(10), JW(10), JX(10), JY(10), JZ(10), KA(10), KB(10), KC(10), KD(10)
670  DATA JU, JV, JW, JX, JY, JZ, KA, KB, KC, KD
680  DIMENSION KE(10), KF(10), KG(10), KH(10), KI(10), KJ(10), KK(10), KL(10), KM(10), KN(10)
690  DATA KE, KF, KG, KH, KI, KJ, KK, KL, KM, KN
700  DIMENSION KO(10), KP(10), KQ(10), KR(10), KS(10), KT(10), KU(10), KV(10), KW(10), KX(10)
710  DATA KO, KP, KQ, KR, KS, KT, KU, KV, KW, KX
720  DIMENSION KY(10), KZ(10), LA(10), LB(10), LC(10), LD(10), LE(10), LF(10), LG(10), LH(10)
730  DATA KY, KZ, LA, LB, LC, LD, LE, LF, LG, LH
740  DIMENSION LI(10), LJ(10), LK(10), LL(10), LM(10), LN(10), LO(10), LP(10), LQ(10), LR(10)
750  DATA LI, LJ, LK, LL, LM, LN, LO, LP, LQ, LR
760  DIMENSION LS(10), LT(10), LU(10), LV(10), LW(10), LX(10), LY(10), LZ(10), MA(10), MB(10)
770  DATA LS, LT, LU, LV, LW, LX, LY, LZ, MA, MB
780  DIMENSION MC(10), MD(10), ME(10), MF(10), MG(10), MH(10), MI(10), MJ(10), MK(10), ML(10)
790  DATA MC, MD, ME, MF, MG, MH, MI, MJ, MK, ML
800  DIMENSION MN(10), MO(10), MP(10), MQ(10), MR(10), MS(10), MT(10), MU(10), MV(10), MW(10)
810  DATA MN, MO, MP, MQ, MR, MS, MT, MU, MV, MW
820  DIMENSION MX(10), MY(10), MZ(10), NA(10), NB(10), NC(10), ND(10), NE(10), NF(10), NG(10)
830  DATA MX, MY, MZ, NA, NB, NC, ND, NE, NF, NG
840  DIMENSION NH(10), NI(10), NJ(10), NK(10), NL(10), NM(10), NO(10), NP(10), NQ(10), NR(10)
850  DATA NH, NI, NJ, NK, NL, NM, NO, NP, NQ, NR
860  DIMENSION NS(10), NT(10), NU(10), NV(10), NW(10), NX(10), NY(10), NZ(10), OA(10), OB(10)
870  DATA NS, NT, NU, NV, NW, NX, NY, NZ, OA, OB
880  DIMENSION OC(10), OD(10), OE(10), OF(10), OG(10), OH(10), OI(10), OJ(10), OK(10), OL(10)
890  DATA OC, OD, OE, OF, OG, OH, OI, OJ, OK, OL
900  DIMENSION OM(10), ON(10), OO(10), OP(10), OQ(10), OR(10), OS(10), OT(10), OU(10), OV(10)
910  DATA OM, ON, OO, OP, OQ, OR, OS, OT, OU, OV
920  DIMENSION OW(10), OX(10), OY(10), OZ(10), PA(10), PB(10), PC(10), PD(10), PE(10), PF(10)
930  DATA OW, OX, OY, OZ, PA, PB, PC, PD, PE, PF
940  DIMENSION PG(10), PH(10), PI(10), PJ(10), PK(10), PL(10), PM(10), PN(10), PO(10), PP(10)
950  DATA PG, PH, PI, PJ, PK, PL, PM, PN, PO, PP
960  DIMENSION PQ(10), PR(10), PS(10), PT(10), PU(10), PV(10), PW(10), PX(10), PY(10), PZ(10)
970  DATA PQ, PR, PS, PT, PU, PV, PW, PX, PY, PZ
980  DIMENSION QA(10), QB(10), QC(10), QD(10), QE(10), QF(10), QG(10), QH(10), QI(10), QJ(10)
990  DATA QA, QB, QC, QD, QE, QF, QG, QH, QI, QJ
1000 DIMENSION QK(10), QL(10), QM(10), QN(10), QO(10), QP(10), QQ(10), QR(10), QS(10), QT(10)
1010 DATA QK, QL, QM, QN, QO, QP, QQ, QR, QS, QT
1020 DIMENSION QU(10), QV(10), QW(10), QX(10), QY(10), QZ(10), RA(10), RB(10), RC(10), RD(10)
1030 DATA QU, QV, QW, QX, QY, QZ, RA, RB, RC, RD
1040 DIMENSION RE(10), RF(10), RG(10), RH(10), RI(10), RJ(10), RK(10), RL(10), RM(10), RN(10)
1050 DATA RE, RF, RG, RH, RI, RJ, RK, RL, RM, RN
1060 DIMENSION RO(10), RP(10), RQ(10), RR(10), RS(10), RT(10), RU(10), RV(10), RW(10), RX(10)
1070 DATA RO, RP, RQ, RR, RS, RT, RU, RV, RW, RX
1080 DIMENSION RY(10), RZ(10), SA(10), SB(10), SC(10), SD(10), SE(10), SF(10), SG(10), SH(10)
1090 DATA RY, RZ, SA, SB, SC, SD, SE, SF, SG, SH
1100 DIMENSION SI(10), SJ(10), SK(10), SL(10), SM(10), SN(10), SO(10), SP(10), SQ(10), SR(10)
1110 DATA SI, SJ, SK, SL, SM, SN, SO, SP, SQ, SR
1120 DIMENSION SS(10), ST(10), SU(10), SV(10), SW(10), SX(10), SY(10), SZ(10), TA(10), TB(10)
1130 DATA SS, ST, SU, SV, SW, SX, SY, SZ, TA, TB
1140 DIMENSION TC(10), TD(10), TE(10), TF(10), TG(10), TH(10), TI(10), TJ(10), TK(10), TL(10)
1150 DATA TC, TD, TE, TF, TG, TH, TI, TJ, TK, TL
1160 DIMENSION TM(10), TN(10), TO(10), TP(10), TQ(10), TR(10), TS(10), TT(10), TU(10), TV(10)
1170 DATA TM, TN, TO, TP, TQ, TR, TS, TT, TU, TV
1180 DIMENSION TW(10), TX(10), TY(10), TZ(10), UA(10), UB(10), UC(10), UD(10), UE(10), UF(10)
1190 DATA TW, TX, TY, TZ, UA, UB, UC, UD, UE, UF
1200 DIMENSION UG(10), UH(10), UI(10), UJ(10), UK(10), UL(10), UM(10), UN(10), UO(10), UP(10)
1210 DATA UG, UH, UI, UJ, UK, UL, UM, UN, UO, UP
1220 DIMENSION UQ(10), UR(10), US(10), UT(10), UV(10), UW(10), UX(10), UY(10), UZ(10), VA(10)
1230 DATA UQ, UR, US, UT, UV, UW, UX, UY, UZ, VA
1240 DIMENSION VB(10), VC(10), VD(10), VE(10), VF(10), VG(10), VH(10), VI(10), VJ(10), VK(10)
1250 DATA VB, VC, VD, VE, VF, VG, VH, VI, VJ, VK
1260 DIMENSION VL(10), VM(10), VN(10), VO(10), VP(10), VQ(10), VR(10), VS(10), VT(10), VU(10)
1270 DATA VL, VM, VN, VO, VP, VQ, VR, VS, VT, VU
1280 DIMENSION VV(10), VW(10), VX(10), VY(10), VZ(10), WA(10), WB(10), WC(10), WD(10), WE(10)
1290 DATA VV, VW, VX, VY, VZ, WA, WB, WC, WD, WE
1300 DIMENSION WF(10), WG(10), WH(10), WI(10), WJ(10), WK(10), WL(10), WM(10), WN(10), WO(10)
1310 DATA WF, WG, WH, WI, WJ, WK, WL, WM, WN, WO
1320 DIMENSION WP(10), WQ(10), WR(10), WS(10), WT(10), WU(10), WV(10), WW(10), WX(10), WY(10)
1330 DATA WP, WQ, WR, WS, WT, WU, WV, WW, WX, WY
1340 DIMENSION WZ(10), XA(10), XB(10), XC(10), XD(10), XE(10), XF(10), XG(10), XH(10), XI(10)
1350 DATA WZ, XA, XB, XC, XD, XE, XF, XG, XH, XI
1360 DIMENSION XJ(10), XK(10), XL(10), XM(10), XN(10), XO(10), XP(10), XQ(10), XR(10), XS(10)
1370 DATA XJ, XK, XL, XM, XN, XO, XP, XQ, XR, XS
1380 DIMENSION XT(10), XU(10), XV(10), XW(10), XX(10), XY(10), XZ(10), YA(10), YB(10), YC(10)
1390 DATA XT, XU, XV, XW, XX, XY, XZ, YA, YB, YC
1400 DIMENSION YD(10), YE(10), YF(10), YG(10), YH(10), YI(10), YJ(10), YK(10), YL(10), YM(10)
1410 DATA YD, YE, YF, YG, YH, YI, YJ, YK, YL, YM
1420 DIMENSION YN(10), YO(10), YP(10), YQ(10), YR(10), YS(10), YT(10), YU(10), YV(10), YW(10)
1430 DATA YN, YO, YP, YQ, YR, YS, YT, YU, YV, YW
1440 DIMENSION YX(10), YY(10), YZ(10), ZA(10), ZB(10), ZC(10), ZD(10), ZE(10), ZF(10), ZG(10)
1450 DATA YX, YY, YZ, ZA, ZB, ZC, ZD, ZE, ZF, ZG
1460 DIMENSION ZH(10), ZI(10), ZJ(10), ZK(10), ZL(10), ZM(10), ZN(10), ZO(10), ZP(10), ZQ(10)
1470 DATA ZH, ZI, ZJ, ZK, ZL, ZM, ZN, ZO, ZP, ZQ
1480 DIMENSION ZR(10), ZS(10), ZT(10), ZU(10), ZV(10), ZW(10), ZX(10), ZY(10), ZZ(10)
1490 DATA ZR, ZS, ZT, ZU, ZV, ZW, ZX, ZY, ZZ
1500 DATA A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z, AA, AB, AC, AD, AE, AF, AG, AH, AI, AJ, AK, AL, AM, AN, AO, AP, AQ, AR, AS, AT, AU, AV, AW, AX, AY, AZ, BA, BB, BC, BD, BE, BF, BG, BH, BI, BJ, BK, BL, BM, BN, BO, BP, BQ, BR, BS, BT, BU, BV, BW, BX, BY, BZ, CA, CB, CC, CD, CE, CF, CG, CH, CI, CJ, CK, CL, CM, CN, CO, CP, CQ, CR, CS, CT, CU, CV, CW, CX, CY, CZ, DA, DB, DC, DD, DE, DF, DG, DH, DI, DJ, DK, DL, DM, DN, DO, DP, DQ, DR, DS, DT, DU, DV, DW, DX, DY, DZ, EA, EB, EC, ED, EE, EF, EG, EH, EI, EJ, EK, EL, EM, EN, EO, EP, EQ, ER, ES, ET, EU, EV, EW, EX, EY, EZ, FA, FB, FC, FD, FE, FF, FG, FH, FI, FJ, FK, FL, FM, FN, FO, FP, FQ, FR, FS, FT, FU, FV, FW, FX, FY, FZ, GA, GB, GC, GD, GE, GF, GG, GH, GI, GJ, GK, GL, GM, GN, GO, GP, GQ, GR, GS, GT, GU, GV, GW, GX, GY, GZ, HA, HB, HC, HD, HE, HF, HG, HH, HI, HJ, HK, HL, HM, HN, HO, HP, HQ, HR, HS, HT, HU, HV, HW, HX, HY, HZ, IA, IB, IC, ID, IE, IF, IG, IH, II, IJ, IK, IL, IM, IN, IO, IP, IQ, IR, IS, IT, IU, IV, IW, IX, IY, IZ, JA, JB, JC, JD, JE, JF, JG, JH, JI, JJ, JK, JL, JM, JN, JO, JP, JQ, JR, JS, JT, JU, JV, JW, JX, JY, JZ, KA, KB, KC, KD, KE, KF, KG, KH, KI, KJ, KK, KL, KM, KN, KO, KP, KQ, KR, KS, KT, KU, KV, KW, KX, KY, KZ, LA, LB, LC, LD, LE, LF, LG, LH, LI, LJ, LK, LL, LM, LN, LO, LP, LQ, LR, LS, LT, LU, LV, LW, LX, LY, LZ, MA, MB, MC, MD, ME, MF, MG, MH, MI, MJ, MK, ML, MN, MO, MP, MQ, MR, MS, MT, MU, MV, MW, MX, MY, MZ, NA, NB, NC, ND, NE, NF, NG, NH, NI, NJ, NK, NL, NM, NO, NP, NQ, NR, NS, NT, NU, NV, NW, NX, NY, NZ, OA, OB, OC, OD, OE, OF, OG, OH, OI, OJ, OK, OL, OM, ON, OO, OP, OQ, OR, OS, OT, OU, OV, OW, OX, OY, OZ, PA, PB, PC, PD, PE, PF, PG, PH, PI, PJ, PK, PL, PM, PN, PO, PP, PQ, PR, PS, PT, PU, PV, PW, PX, PY, PZ, QA, QB, QC, QD, QE, QF, QG, QH, QI, QJ, QK, QL, QM, QN, QO, QP, QQ, QR, QS, QT, QU, QV, QW, QX, QY, QZ, RA, RB, RC, RD, RE, RF, RG, RH, RI, RJ, RK, RL, RM, RN, RO, RP, RQ, RR, RS, RT, RU, RV, RW, RX, RY, RZ, SA, SB, SC, SD, SE, SF, SG, SH, SI, SJ, SK, SL, SM, SN, SO, SP, SQ, SR, SS, ST, SU, SV, SW, SX, SY, SZ, TA, TB, TC, TD, TE, TF, TG, TH, TI, TJ, TK, TL, TM, TN, TO, TP, TQ, TR, TS, TT, TU, TV, TW, TX, TY, TZ, UA, UB, UC, UD, UE, UF, UG, UH, UI, UJ, UK, UL, UM, UN, UO, UP, UQ, UR, US, UT, UV, UW, UX, UY, UZ, VA, VB, VC, VD, VE, VF, VG, VH, VI, VJ, VK, VL, VM, VN, VO, VP, VQ, VR, VS, VT, VU, VW, VX, VY, VZ, WA, WB, WC, WD, WE, WF, WG, WH, WI, WJ, WK, WL, WM, WN, WO, WP, WQ, WR, WS, WT, WU, WV, WW, WX, WY, WZ, XA, XB, XC, XD, XE, XF, XG, XH, XI, XJ, XK, XL, XM, XN, XO, XP, XQ, XR, XS, XT, XU, XV, XW, XX, XY, XZ, YA, YB, YC, YD, YE, YF, YG, YH, YI, YJ, YK, YL, YM, YN, YO, YP, YQ, YR, YS, YT, YU, YV, YW, YX, YY, YZ, ZA, ZB, ZC, ZD, ZE, ZF, ZG, ZH, ZI, ZJ, ZK, ZL, ZM, ZN, ZO, ZP, ZQ, ZR, ZS, ZT, ZU, ZV, ZW, ZX, ZY, ZZ

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Data strip:

```

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

```

Number of frequency values = 15

```

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

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NOT REPRODUCIBLE

The impulse response in a transmission line which is terminated by its characteristic impedance. R and G are frequency-dependent.

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5. Conclusion

The calculations show that direct current signalling with high speeds is possible over an appropriate cable. However, the long transient-times will shift the "0" line independently of the duration and distance of the signal pulse. It may therefore be necessary to carry out a correction; the response for the lower-frequencies especially has to be reduced. A correction network for a cable is dealt with in a thesis for the Institute for Transmission Techniques, NTH. (SA1)

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